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GFR Estimation in Adolescents and Young Adults

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ABSTRACT

The performance of creatinine-based equations to obtain the estimated GFR in adolescents and young adults is poorly understood. We assessed creatinine-based GFR estimating equations in a cross-section of 751 adolescents and young adults (1054 measurements), using inulin clearance (measured GFR [mGFR]) as the reference method. We evaluated the following: Cockcroft-Gault, four-variable Modified Diet in Renal Disease, and the Chronic Kidney Disease Epidemiology Collaboration equations for adult participants, as well as the Schwartz 2009 and Schwartz-Lyon equations for pediatric age groups. Participants ranged in age from 10 to 26 years (mean 16.8 years); we divided the population into four groups according to age (10–12 years, 13–17 years, 18–21 years, and 21–25 years). Evaluation of the agreement between these formulas and mGFR (*e.g.*, correlation, Bland–Altman plots, bias, and accuracy) showed that there was a good correlation between mGFR and both pediatric formulas in all age groups, whereas the adult formulas substantially overestimated mGFR. In conclusion, we recommend the use of pediatric equations to estimate GFR from childhood to early adulthood.

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GFR is the most widely used index of renal function; therefore, accurate estimation of GFR is often needed in both clinical practice and research. Reference methods to determine GFR require an exogenous marker, such as inulin, ^{51}Cr-EDTA, iohexol, or iothalamate, and cannot be used in daily practice because of its complexity and costs.[1] Plasma creatinine (PCr) is the most commonly used biochemical marker of renal function. However, several factors other than GFR can affect PCr, including its generation from muscle metabolism, tubular secretion, and the creatinine assay method. In addition, PCr is insensitive for detection of mild to moderate reductions of GFR.[2] Therefore, clinical guidelines on CKD management recommend the use of GFR estimating equations as an alternative noninvasive method to estimate GFR.[3] Several formulas have been developed for daily clinical practice. Among them, the Cockcroft-Gault (CG) formula and the Modification of Diet in Renal Disease (MDRD) simplified formula are the most frequently used in adults.[4,5] More recently, the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation was developed to reduce bias compared with the MDRD equation, especially among patients with an estimated GFR (eGFR) >60 ml/min per 1.73 m^2.[6] The original Schwartz formula developed in children in 1976 has been recently adapted to current methods of PCr assay and its use is now recommended to estimate GFR in children.[7,8] Another locally adapted Schwartz formula to our creatinine assay method has very good agreement with standardized creatinine measurement.[9,10] However, all of these adult or pediatric equations have been determined for a specific population and their external validity in adolescents and young adults is limited. Therefore, this study was conducted to assess the performance of the most commonly used creatinine-based formulas in adults and children in a large cross-sectional cohort of adolescents and young adults with a broad spectrum of GFRs.

We analyzed data from 1054 inulin clearance measurements in 751 patients. Demographic and clinical characteristics of patients at the time of GFR assessment—including age, height, body weight, body mass index, and body surface area—are presented in Table 1. Our results showed that 11% of patients had weight or height

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Table 1. Description of the whole population and characteristics of each age group

Characteristic	All	Group 1 (10–12 yr)	Group 2 (13–17 yr)	Group 3 (18–21 yr)	Group 4 (22–25 yr)
n	1054	225	322	262	245
Male (%)	54	58	57	50	52
mGFR (ml/min per 1.73 m^2)	91.0 (66.0–109.7)	95.0 (73.9–113.0)	87.0 (66.5–108.7)	94.0 (69.0–112.0)	84.0 (62.0–105.0)
Age (yr)	17.0 (13.0–21.0)	11.0 (10.0–12.1)	15.0 (14.2–16.1)	20.0 (19.1–20.3)	23.1 (22.3–24.0)
Weight (kg)	52.0 (41.0–61.3)	34 (28.2–39.5)	51.0 (43.1–59.1)	56.0 (49.0–65.0)	60.0 (52.0–70.1)
Weight percentile		30.8 (8.8–64.2)	37.2 (9.2–67.6)		
Height (cm)	151.4 (149.7–170)	140.7 (134.0–147.0)	160.0 (152.0–166.5)	166.0 (159.0–174.0)	169.0 (161.0–175.0)
Height percentile		28.1 (8.7–67.7)	34.5 (5.6–63.7)		
BSA (m^2)	1.5 (1.3–1.7)	1.1 (1.0–1.2)	1.5 (1.3–1.6)	1.6 (1.4–1.7)	1.7 (1.5–1.8)
BMI (kg/m^2)	19.7 (17.4–21.9)	16.7 (15.3–18.8)	19.5 (17.5–21.8)	20.6 (18.6–22.4)	21.1 (19.3–23.6)
PCr (μmol/L)	67.6 (54.4–91.1)	51.6 (44.1–61.0)	66.7 (54.4–84.2)	73.7 (61–95.8)	83.6 (64.8–106.1)
KDOQI classification					
1	541 (51)	134 (60)	149 (46)	144 (55)	114 (46)
2	312 (30)	59 (26)	109 (34)	71 (27)	73 (30)
3	178(17)	29 (13)	57 (18)	42 (16)	50 (20)
4–5	23 (2)	3 (1)	7 (2)	5 (2)	8 (4)
Diagnosis					
glomerulopathies	217 (20)	35 (15)	71 (22)	58 (22)	53 (22)
tubulointerstitial disease	260 (25)	53 (24)	57 (18)	71 (27)	79 (32)
kidney transplant recipients	227 (21)	35 (15)	81 (25)	48 (18)	63 (26)
others	350 (34)	102 (46)	113 (35)	85 (33)	50 (20)

Values are median (IQR) or *n* (%) unless otherwise specified. BSA, body surface area; BMI, body mass index.

under the third percentile. Diagnoses included glomerular disease (20%), tubulointerstitial disease (26%), kidney transplant recipients (19%), and others (35%). The number of blacks was insufficient to analyze the race component in either series. The median PCr and measured GFR (mGFR) for all participants were 67.6 μmol/L (range, 54.4–91.1) and 91.0 ml/min per 1.73 m^2 (range, 66.0–109.7), respectively. According to the National Kidney Foundation Kidney Disease Outcomes Quality Initiative (KDOQI) classification, 51%, 30%, 17%, and 2% of patients had stage 1, 2, 3, or 4–5 CKD, respectively.

Mean eGFR as well as mean ratios (eGFR/mGFR), accuracies (10% and 30%), and univariate correlation coefficients between mGFR and eGFR obtained with the PCr-based formulas in the whole cohort are summarized in Table 2. Figures 1 and 2 correspond to the different correlation and Bland–Altman plots obtained in the whole population for adult and pediatric formulas, respectively. The adult formulas (*i.e.,* CG, MDRD, and CKD-EPI) substantially overestimated mGFR in the whole population, with mean ratios of 1.42 ± 0.35, 1.41 ± 0.47, and 1.38 ± 0.36 ml/min per 1.73 m^2, respectively. That is, the adult formulas overestimated mGFR by 42%, 41%, and 38%, respectively. At the same time, the mean ratios for the pediatric formulas (*i.e.,* 2009 Schwartz and Schwartz-Lyon) were 1.00 ± 0.22 and 0.95 ± 0.20 ml/min per 1.73 m^2, respectively. The Schwartz 2009 has no over- or underestimation of mGFR, and Schwartz-Lyon underestimated the mGFR by 5%. The correlation between eGFR and mGFR according to the Bland–Altman plot of all formulas highlighted a strong overestimation of GFR by the CG, MDRD, and CKD-EPI formulas, with marked scattering of values (Figure 1) compared with the pediatric formulas (Figure 2). Accuracies (10% and 30%) were much lower with adult formulas than with pediatric formulas (Table 2).

Mean eGFR as well as mean ratios, accuracies (10% and 30%), and univariate correlation coefficients between mGFR and eGFR obtained with the PCr-based formulas according to each age group are summarized in Table 2. Mean ratios were significantly higher with adult formulas than with pediatric formulas even for patients aged >17 years. The Schwartz 2009 and Schwartz-Lyon formulas had superior accuracy (10% and 30%) in all populations and in each age group. The performance of adult formulas was comparable with those of pediatric formulas only for patients aged >21 years.

Results for mean eGFR, mean ratio, and accuracies (10% and 30%) are presented in Table 3 with respective SDs. Pediatric formulas (*i.e.,* Schwartz 2009 and Schwartz-Lyon) performed better than adult formulas in the whole normal GFR population with mean eGFR/mGFR ratios of 0.92 ± 0.16 and 0.89 ± 0.16 ml/min per 1.73 m^2, respectively. This superiority was found at any stage of CKD. The accuracies (10% and 30%) were similar for pediatric formulas when mGFRs were >30 ml/min per 1.73 m^2, but were poor when mGFR was below this value.

The accurate and repeated estimation of GFR is a major concern in patients, especially during the transition period from childhood to adulthood in which rapid growth and changes of body composition occur. Reference methods for assessing GFR are difficult to perform and estimations of GFR by PCr-based formulas are widely used in clinical practice. However, if the performance of the equations to estimate GFR has been largely studied in children and in adults,[11] it has

Table 2. Mean bias and accuracies according to age groups and equations

Group	CG	MDRD	CKD-EPI	Schwartz 2009	Schwartz-Lyon
All measurements (*n*=1054)					
mGFR=88.7±30.8					
eGFR	123.0±45.3	122.9±56.6	116.7±34.0	85.8±27.7	81.8±27.7
correlation coefficient (*r*)	0.83	0.76	0.80	0.85	0.86
mean ratio (eGFR/mGFR)	1.42±0.35	1.41±0.47	1.38±0.36	1.00±0.22	0.95±0.20
95% limits of agreement	0.73, 2.10	0.48, 2.32	0.69, 2.06	0.55, 1.45	0.55, 1.34
10% accuracy	15	22	18	38[a]	36[a]
30% accuracy	41	50	49	86[a]	87[a]
Group 1 (10–12 yr) (*n*=225)					
mGFR=93.4±29.3					
eGFR	150.9±45.2	179.3±59.0	144.6±25.6	98.6±25.6	88.7±25.0
correlation coefficient (*r*)	0.87	0.84	0.84	0.88	0.89
mean ratio (eGFR/mGFR)	1.65±0.32	1.95±0.42	1.65±0.39	1.10±0.21	0.98±0.18
95% limits of agreement	1.02, 2.28	1.13, 2.77	0.89, 2.41	0.69, 1.51	0.63, 1.33
10% accuracy	1	1	3	47[a]	48[a]
30% accuracy	10	4	17	86	92[b]
Group 2 (13–17 yr) (*n*=322)					
mGFR=87.3±32.5					
eGFR	127.1±45.4	125.3±50.9	119.9±32.5	87.2±28.3	85.7±29.7
correlation coefficient (*r*)	0.88	0.86	0.85	0.89	0.89
mean ratio (eGFR/mGFR)	1.50±0.33	1.46±0.37	1.44±0.32	1.04±0.21	1.01±0.20
95% limits of agreement	0.85, 2.15	0.74, 2.18	0.81, 2.07	0.63, 1.45	0.62, 1.40
10% accuracy	6	14	10	41[a]	37[a]
30% accuracy	31	41	38	88	90
Group 3 (18–21 yr) (*n*=262)					
mGFR=90.4±30.1					
eGFR	113.2±39.3	102.9±40.1	106.9±30.5	82.0±26.4	79.4±27.3
correlation coefficient (*r*)	0.85	0.85	0.86	0.86	0.85
mean ratio (eGFR/mGFR)	1.28±0.29	1.16±0.30	1.23±0.27	0.94±0.22	0.90±0.41
95% limits of agreement	0.71, 1.85	0.57, 1.75	0.96, 1.56	0.51, 1.37	0.49, 1.31
10% accuracy	25	36	27	32	28
30% accuracy	59	75	69	84[a]	83[a]
Group 4 (22–25 yr) (*n*=245)					
mGFR=84.1±30.3					
eGFR	102.5±35.5	89.3±31.8	97.3±28.4	76.0±25.7	73.0±25.2
correlation coefficient (*r*)	0.85	0.85	0.86	0.86	0.85
mean ratio (eGFR/mGFR)	1.27±0.31	1.10±0.27	1.21±0.28	0.94±0.21	0.90±0.23
95% limits of agreement	0.66, 1.87	0.57, 1.63	0.66, 1.76	0.53, 1.35	0.45, 1.35
10% accuracy	29	36	33	33	31
30% accuracy	64	78	72	85	82

mGFR and eGFR are measured in milliliters per minute per 1.73 m^2.
[a] $P<0.05$ between pediatric formulas and other equations, favoring pediatric equations, but without significant difference between Schwartz 2009 and Schwartz-Lyon.
[b] $P<0.05$ between pediatric formulas and other equations, favoring Schwartz-Lyon. All results are expressed as mean ± SD.

been very rarely evaluated in adolescents and young adults. In this study, we compared five GFR estimating equations (CG, MDRD, CKD-EPI, Schwartz 2009, and Schwartz-Lyon) with measurements of inulin clearance in a large cross-sectional adolescent and young adult population.

The main findings of this study are as follows: (*1*) the demonstration of the validity of the 2009 published "new bedside Schwartz" formula in a population of adolescents and young adults with different characteristics than the original one, mainly in terms of GFR and age; (*2*) the validation of the "locally adapted" Schwartz formula in this population; and (*3*) the demonstration that adult formulas should not be used in adolescents.

The Schwartz 2009 formula is very close to our locally adapted formula, but it does not take age into account, especially in adolescent boys. Indeed, Schwartz *et al.* developed this formula in a cohort of 349 North American children with mild to severe CKD (median GFR 41 ml/min per 1.73 m^2) and notable growth retardation. In contrast, the Schwartz-Lyon formula has been developed in the same way than the original Schwartz formula, that is with different coefficients according to age and sex (k=33 for females and males aged <13 years and k=37 for males aged ≥13 years) and has been validated in a pediatric population of 252 patients aged 10.7±4.0 years (range, 4.4–19.9) with mild or any renal insufficiency (mean mGFR 101±32

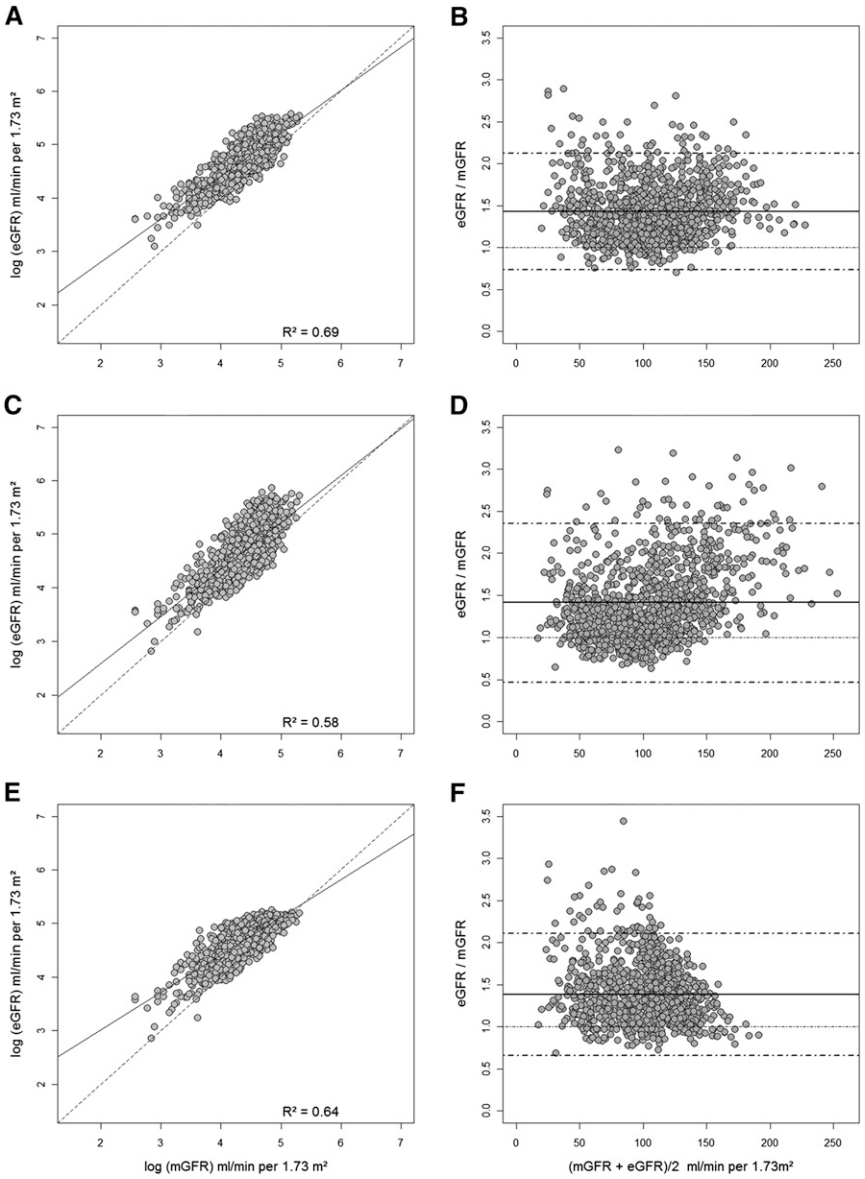

Figure 1. Comparison between different adult-based formulas (eGFR) and inulin clearance (mGFR). The left column shows Univariate relationship plots of the (A) CG, (C) MDRD, and (E) CKD-EPI formulas, using logarithmic transformation. The right column shows Bland–Altman plots of the (B) CG, (D) MDRD, and (F) CKD-EPI formulas, using ratios of eGFR/mGFR against (eGFR + mGFR)/2.

ml/min per 1.73 m^2) and no significant growth retardation.[10] The results of our study demonstrated that the 2009 Schwartz and Schwartz-Lyon are bedside formulas that had superior accuracies (10% and 30%) than the adult formulas in the whole population and in each age group. In addition, they are simpler to use and they can therefore be reliable in an extended population from about 5 to 25 years, which allow an easy follow-up of renal function. Comparison of the two pediatric formulas showed that in the whole population and for patients aged ≥13 years, they have a similar performance to estimate GFR with comparable concordance (mean ratio), correlation coefficients, and accuracies. However, in children the performance was slightly improved ($P<0.05$) (Table 2), likely due to the specific *k* coefficient used in these subgroups of patients.

Despite the good performance of the pediatric formulae, an underestimation of GFR of about 10% is observed in patients with normal renal function (GFR ≥90). These results are in accordance with those of Fadrowski *et al.*, which suggested that the bedside Schwartz 2009 formulae may underestimate renal function in normal patients with 8.9% of normal adolescents having an eGFR <75 ml/min per 1.73m^2.[12] Chavers *et al.* found comparable results with the Chronic Kidney Disease in Children formula, which includes PCr, cystatin C, and BUN.[13]

The three most used creatinine-based formulas in adults (CG, MDRD, CKD-EPI) considerably overestimate the true GFR in the whole population, probably due to anthropometry. The overestimation of GFR by adult formulas was reduced after 18 years of age but was still present in patients aged between 22 and 26 years, whereas children's formulas tended to underestimate GFR of about 10%. In fact, the adult creatinine–based formulas were developed in middle-aged or aged populations of patients with various pathologic conditions and were not designed to study renal function in young adults or adolescents. The CG formula was developed in 1976 by using the mean 24-hour urine creatinine excretion from two urine collections obtained in 249 adult men aged from 18 to 92 years. The use of the CG equation for children and adolescents is controversial.[11,14] The MDRD study prediction equation was developed in 1628 patients (males and females) with a mean age of 50.6 ±12 years and a mean GFR of 39.8±21.2 ml/min per 1.73 m^2 and included age, sex, and race to account for average differences in muscle mass in subgroups.[15] The MDRD formula was re-expressed in 2005 using PCr standardized to reference methods.[5] MDRD equation performance to estimate GFR in adults with moderate to severe CKD is now accepted worldwide,[3] but is grossly inaccurate in children and not validated under 18 years of age.[11,14,16] More recently, the CKD-EPI equation has been developed using data from 26 studies (12,150 patients with a mean age of 47–50 years

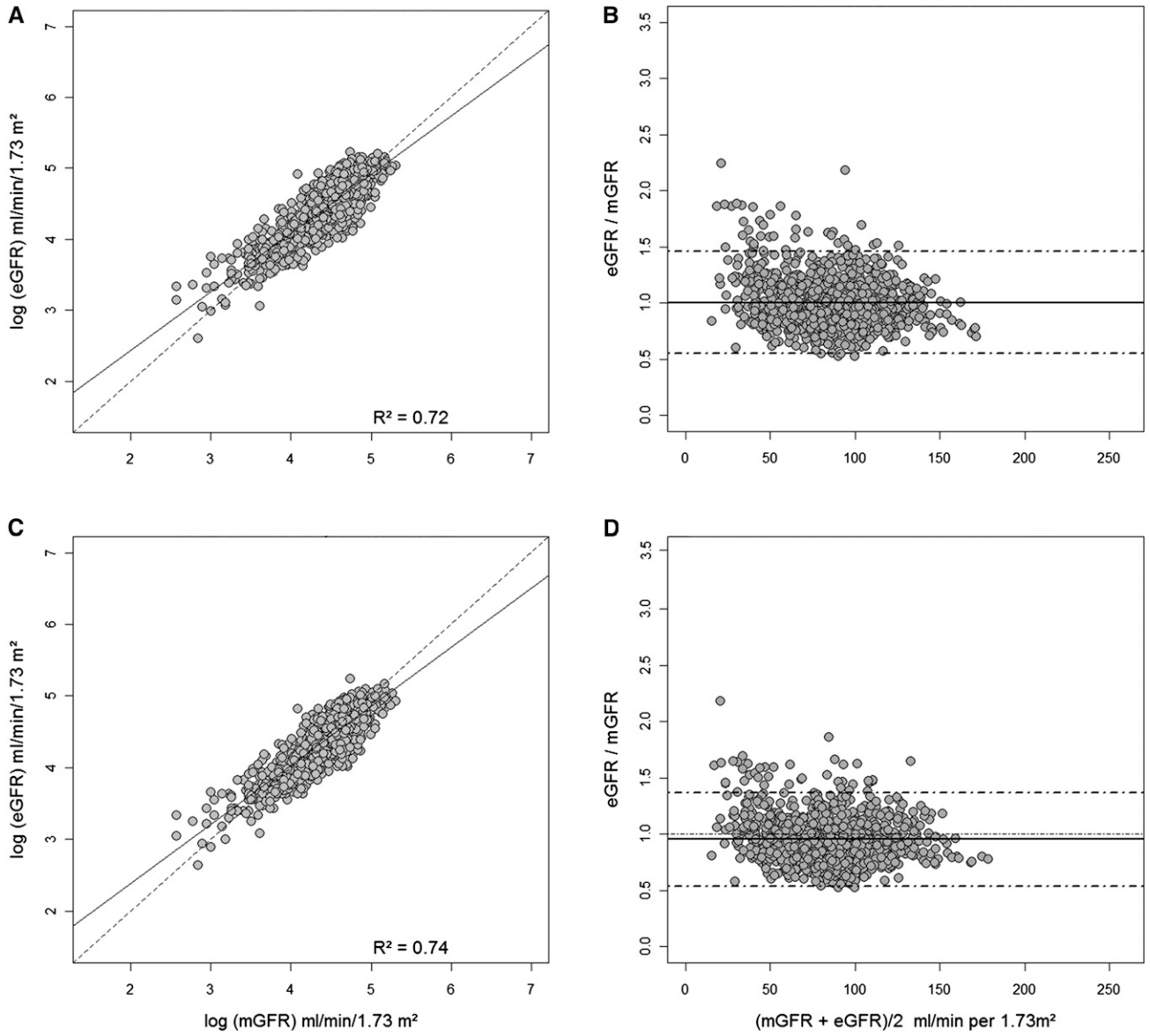

Figure 2. Comparison between pediatric-based formulas (eGFR) and inulin clearance (mGFR). The left column shows univariate relationship plots of the (A) Schwartz 2009 and (C) Schwartz-Lyon formulas, using logarithmic transformation. The right column shows Bland–Altman plots of the (B) Schwartz 2009 and (D) Schwartz-Lyon formulas, using ratios of eGFR/mGFR against (eGFR + mGFR)/2.

and a mean GFR of 67 ±40 ml/min per 1.73 m^2).[6] However, the number of adolescents and young adults is limited in these studies and equations has not been adapted to this specific population. In the adult formulas, the term age forms a central component in order to integrate that muscle mass decreases with time resulting in higher eGFR in younger participants. However, the opposite is true for children, whose muscle mass increases with age and is, in fact, more closely correlated with height than age. Therefore, it is logical that adult creatinine-based equations (*i.e.,* CG, simplified MDRD, and CKD-EPI) overestimate GFR in adolescent and young adults. Several studies reported that the CG or MDRD equation tends to underestimate GFR when renal insufficiency is light or moderate (*i.e.,* GFR >60 ml/min per 1.73 m^2),[17] and the CKD-EPI equation was proposed to increase the precision of eGFR, especially when GFR is in the higher range.[6] The overestimation due to the inadequate role of age in adult formulas is likely much more important than the expected underestimation of GFR due to the higher GFR of our population compared with those of the training data sets of the MDRD and CKD-EPI. This is confirmed by the progressive decrease of the overestimation of GFR from group 1 to group 4 (Table 2). In conclusion, adult creatinine-based equations (*i.e.,* CG, simplified MDRD, and CKD-EPI) are not reliable in adolescents and young adults and should not be use to estimate GFR in clinical practice.

Table 3. Mean bias and accuracies according to KDOQI classification and equations

KDOQI Classification	CG	MDRD	CKD-EPI	Schwartz 2009	Schwartz-Lyon
Stage 1: GFR ≥90 (*n*=541)					
mGFR=113.4±18.1					
eGFR	150.5±37.0	152.1±53.9	136.0±21.0	103.4±20.4	99.6±21.0
mean ratio (eGFR/mGFR)	1.33±0.29	1.35±0.45	1.22±0.21	0.92±0.16	0.89±0.16
10% accuracy	19	25	26	41[a]	35[a]
30% accuracy	51	55	66	91[a]	90[a]
Stage 2: 60< GFR ≥90 (*n*=312)					
mGFR=75.2±8.4					
eGFR	110.5±28.8	110.2±38.9	113.2±26.4	78.4±17.8	74.0±17.2
mean ratio (eGFR/mGFR)	1.47±0.35	1.46±0.48	1.50±0.33	1.04±0.21	0.98±0.20
10% accuracy	12	19	10	39[a]	37[a]
30% accuracy	34	47	32	84[a]	86[a]
Stage 3: 30< GFR ≥60 (*n*=178)					
mGFR=46.6±8.4					
eGFR	71.5±19.0	67.4±24.1	73.7±23.6	51.9±13.3	48.0±11.5
mean ratio (eGFR/mGFR)	1.55±0.35	1.45±0.46	1.60±0.46	1.12±0.25	1.05±0.21
10% accuracy	7	20	8	32[a]	36[a]
30% accuracy	29	41	30	80[b]	87[b]
Stages 4–5: GFR <30 (*n*=23)					
mGFR=22.2±4.7					
eGFR	44.4±12.3	37.7±12.1	40.8±13.5	32.5±9.0	29.9±8.1
mean ratio (eGFR/mGFR)	2.03±0.49	1.7±0.51	1.80±0.54	1.48±0.36	1.36±0.32
10% accuracy	0	4	4	9	22
30% accuracy	4	30	22	39	43

mGFR and eGFR are measured in milliliters per minute per 1.73 m^2.

[a] $P<0.05$ between pediatric formulas and other equations, favoring pediatric formulas, but without significant difference between Schwartz 2009 and Schwartz-Lyon.

[b] $P<0.05$ between pediatric formulas and other equations, favoring Schwartz-Lyon. All results are expressed in mean ± SD. CKD stages 4–5 were combined due to the small number of patients.

We recommend the use of pediatric GFR prediction equations, especially the Schwartz 2009, to estimate and to follow GFR from childhood to early adulthood.

CONCISE METHODS

Patients

We compared eGFR using various formulas based on PCr with the results of mGFR, *i.e.,* inulin clearance in a retrospective cross-sectional cohort of 751 patients (1054 measurements) which included all of the patients aged 10–25.9 years referred to our center between July 2003 and July 2010 to perform inulin clearance for suspected or established renal dysfunction. An appropriate informed consent was obtained from all patients and/or their families. Height, weight, and age were recorded and for patients aged <18 years, and height and body weight percentiles were expressed in medians and IQRs, according to the Centers for Disease Control and Prevention body weight and height for age and sex growth charts.[18] Growth retardation was defined by a height and/or body weight below the third percentile. The whole population was divided into four groups according to age: 10–12 years, 13–17 years, 18–21 years, and 22–25 years. The groups were then further divided by renal function according to the KDOQI classification as follows: stage 1 (mGFR ≥90), stage 2 (60≤ mGFR <90), stage 3 (30≤ mGFR <60), and stage 4–5 (mGFR <30). Stage 4–5 CKD data were combined due to the small number of patients.

PCr Measurements

PCr was obtained from a kinetic colorimetric compensated Jaffe technique (Roche Modular, Meylan, France) for which the imprecision of the assay method was checked (intra-assay coefficient was 0.7%; interassay coefficients were 4.0% at low concentration PCr (45–60 μmol/L) and 1.5% at high concentration PCr (580 μmol/L), respectively). All PCr measurements were performed with the same method over the entire study period. The results for PCr were standardized by linear regression adjustment of the concentrations obtained by the compensated Jaffé assay and the concentrations obtained by liquid chromatography-mass spectrometry (LCMS). Briefly, the LCMS apparatus was calibrated with three European standards (BCR; Bureau community Reference 573, 574 and 575) and two American standards (Standard Reference Material) in which creatinine concentrations ranged from 66.5 to 404 μmol/L. The parameters for the linear regression line were obtained for 54 patients with serum creatinine values ranging from 41 to 220 μmol/L; 94.2% (993) of our PCr values were within this range. Calibration equation was as follows: standardized serum creatinine = 0.9395 × (Jaffé compensated serum creatinine in μmol/L) + 4.6964. The intercept (4.6964; 95% CI, −2.4619 to 11.8656) and slope (0.9395; 95% CI, 0.8719–1.0072) were not significantly different from 0 and 1, respectively. The coefficient of correlation (r) was 0.97. Mean difference between LCMS and compensated Jaffé was 1.24±10.05 μmol/L. Stability of the PCr assays was assessed during the study. Blinded ProBioQal controls were

tested every 5 weeks and a nationwide-blinded control was tested each year.[19]

GFR Measurement

The GFR was measured by the renal clearance of inulin method (polyfructosan, Inutest; Fresenius Kagi, Graz, Austria). A standard technique was used by a trained staff with a continuous infusion after a priming dose of 30 mg/kg polyfructosan. Water diuresis was induced by oral administration of 5 ml/kg of water followed by 3 ml/kg every 30 minutes combined with an intravenous infusion of 0.9% sodium chloride. This enabled the patients to spontaneously empty their bladder every 30 minutes; patients needing intermittent urethral catheterization were excluded from this study. Three to four urine samples were collected and a blood sample was drawn mid-way through each collection period. The clearance values, calculated by the standard UV/P formula, were obtained from the mean values of the three to four clearance periods. Measurements of plasma and urine polyfructosan were performed using the same enzymatic method[20] for which we previously checked the imprecision of the assay method (within-run precision values in plasma and urine of 0.3% and 0.7%, respectively; between-run precision values were 3.5%, 1.6%, and 2.4% at mean polyfructosan values of 117, 198, and 285 mg/L, respectively).[18] The results were expressed to 1.73 m^2, according to the Dubois formula: body surface area = $height^{0.725} \times weight^{0.425} \times 0.007184$.[21]

GFR Estimation

GFR was estimated using five formulas: CG,[4] simplified MDRD,[5] CKD-EPI,[6] 2009 Schwartz (bedside),[7] and Schwartz-Lyon.[10] The eGFR was normalized by body surface area and expressed in milliliters per minute per 1.73 m^2. Standardized creatinine values were used for the calculations of simplified MDRD, CKD-EPI, and 2009 Schwartz formulas. The equations used to determine eGFR are presented in Table 4.

Statistical Analyses

Statistical analyses were performed in the entire population and in each group separately. Performance of each eGFR equation was assessed in terms of mean ratio (eGFR/mGFR), the Pearson correlation coefficient (r), and accuracy (proportion of eGFR results within 10% and 30% of mGFR).[3] The mean ratio was used in order to correct the variance of bias that was not constant.[22] The eGFR mean ratios were compared each other using the paired t test. The accuracies of the eGFR equations were compared using McNemar's test. We used the Kolomogorov–Smirnov and Kruskal–Wallis tests to evaluate the normalization of quantitative data. Bland–Altman plots illustrated the agreement between eGFR calculated by different formulas and the reference mGFR. A value of $P<0.05$ was considered to indicate statistical significance. These calculations were performed with IBM SPSS software (version 17.0 for Windows).

Table 4. Equations used to determine eGFR

Name	Formula
CG adjusted to BSA[4]	eGFR = (1.73/BSA) × [(140 – age) × weight]/72 × (PCr × 0.0113) × 0.85 if female
MDRD[5]	eGFR = 175 × $(PCr \times 0.0113)^{-1.154}$ × $(age)^{-0.203}$ ×0.742 if female ×1.212 if black
CKD-EPI[6]	k1 × $[(PCr/88.5)/k2)]^{k3}$ × 0.993^{age} with k1 = 141 or 144 for white male and female, respectively K1 = 163 or 166 for black male and female, respectively k2 = 0.7 or 0.9 for female and male, respectively k3 = −0.411 or −1.209, for male with PCr ≤80 and PCr >80 μmol/L, respectively K3 = −0.329 or −1.209, for female with PCr ≤62 and PCr >62 μmol/L, respectively
Schwartz 2009[7]	eGFR = k × height/PCr k = 36.5
Schwartz-Lyon[10]	eGFR = k × height/PCr k = 37 if males aged >13 yr k = 33 if others

eGFR is measured in milliliters per minute per 1.73 m^2. PCr is expressed in micromoles per liter; height in centimeters, weight in kilograms, and age in years. BSA, body surface area.

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DISCLOSURES

None.

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